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FINAL REPORT

EVALUATION OF POLARIZER
FOR USE IN
OBLIQUE AERIAL PHOTOGRAPHY

by

[redacted]

[redacted]

[redacted]

ABSTRACT

The purpose of this project was to test and evaluate the use of a polarizer in oblique aerial black-and-white photography and to determine whether the results of such tests indicate that general use of the polarizer would be beneficial. A series of controlled flight tests were made. On each flight, a specific target was chosen and two simultaneous photographs of the target - one polarized and one nonpolarized - were taken. Selected negatives and enlargements of these photographs are presented herewith for visual comparison. The results confirm that a polarizer can affect the contrast of aerial photographs and that the contrast is, in most cases, improved. In some situations, however, contrast is actually reduced. Examples of both are cited.

CONTENTS

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ILLUSTRATIONS

SECTION I

INTRODUCTION

This is the final report of a flight test program to evaluate a manually oriented polarizer for use in oblique* aerial photography. The program considered only black-and-white photography using Kodak type 3401 film. Two sun elevations and two atmospheric haze conditions were included, and the camera orientation was varied. Thus, the flight test program included a variety of situations which can occur in an aerial photographic mission.

The results of the program are presented as original negatives with enlarged prints and annotation of selected negatives. The results include examples of each of three ways in which a polarizer can affect the contrast of an aerial photograph. A discussion of these three ways is included in Section II of this report.

The results of the program confirm that a polarizer can affect the contrast of aerial photographs. In most instances there is an improvement in contrast. However, in some situations the contrast is actually reduced. Examples of both cases are cited in the prints.

NOTE

It is absolutely necessary to refer to the set of original negatives supplied with this report in order to obtain maximum information from the data presented herein.

* Oblique angles are measured from the vertical throughout this report.

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SECTION II

THEORETICAL DISCUSSION

The purpose of a polarizer in aerial photography is to improve the contrast of the optical image at the film plane of the camera. It is the optical contrast rather than the photographic contrast (or gamma) which is affected by a polarizer. The photographic contrast is completely independent of polarization effects. Of course, the contrast of the resulting photograph is improved when the optical contrast is increased.

There are three fundamental ways in which a polarizer can affect the contrast of aerial photographic imagery. First, a polarizer can be used to reduce the contrast degrading effect of atmospheric scatter or haze. Second, a polarizer can be used to reduce the flare caused by specular reflections from water. Third, a polarizer can be used to alter the optical contrast between objects in the scene whose images are unequally polarized. We shall consider each of the three ways in more depth.

A polarizer is useful in penetrating haze when the haze radiation is polarized differently (either in magnitude or direction) than the image-forming radiation from the scene. Then, the polarizer can be oriented perpendicularly to the direction of haze polarization, improving the ratio of image-forming radiation to haze radiation. The result is that the optical contrast, especially in the shadows, is increased.

Two types of scatter combine to form the haze encountered in aerial photography. The first type is the result of scatter by molecules and other particles whose dimensions are small compared to the wavelength of the scattered photons. It is this type of scatter which causes the blue sky and the blue haze which is observed on a clear day. Molecular scatter is highly polarized in certain directions and can be greatly reduced by a properly oriented polarizer.

The theory of molecular scatter was developed by Lord Rayleigh[1] and is often referred to as Rayleigh scatter. The most useful result from this theory is that the polarization P of light after single scattering events is related to the scatter angle θ by the equation

1. Max Born and Emil Wolf, Principles of Optics, Third (Revised) Edition, Pergamon Press, 1965, pp. 652-656.

$$P = \frac{2 \sin^2 \theta}{1 + \sin^2 \theta} \qquad (1)$$

The scatter angle is defined as the angle between the direction of travel of a photon, before and after the scattering event. The direction of polarization is with the electric vector perpendicular to the plane of observation, i.e., the plane in which the incoming and scattered photon travel. A plot of Equation (1), along with an illustration of the scatter angle, is presented in Figure 1. Notice that the polarization is unity at a scatter angle of 90 degrees. A polarizer is very effective against Rayleigh scatter when the scattered radiation is this highly polarized.

The second type of particle which is important in atmospheric scatter is the aerosol particle with dimensions in the neighborhood of, and larger than, the wavelength of the scattered light. The most common particles of this type are condensed water vapor; but other such particles include smoke, dust, volcanic ash, and smog.

The theory of aerosol scatter was developed by Mie; therefore scatter by this type of particle is called Mie scatter. The polarization of Mie scatter is a complex function of the optical constants of the material, the particle size, and the scatter angle. Because these particles are statistically distributed in size and space, as well as time, a quantitative prediction of the gross scattering properties is not worthwhile, at least not for our purposes. There are, however, two useful qualitative results from the Mie theory which are relevant to this program. First, the scattered radiation is partially polarized, but never as highly as molecular scatter. Second, the scatter is polarized in the same direction as Rayleigh scatter. Thus, a polarizer is oriented in the same direction to minimize the haze resulting from either Rayleigh or Mie scatter.

In the atmosphere, the situation is more complicated than simple individual scattering events by two kinds of particles. The concentration of aerosol particles can vary widely. Also, the polarization, as predicted by Rayleigh and Mie, is lowered by the occurrence of multiple scattering. As a result, even on the clearest day, the sky polarization perpendicular to the sun is not unity. The probability of multiple scatter is a function of the aerosol concentration of the atmosphere.

Thus, the polarization of atmospheric haze is a function of the scatter angle (for first scatter events) and the concentration and distribution of aerosol particles. These

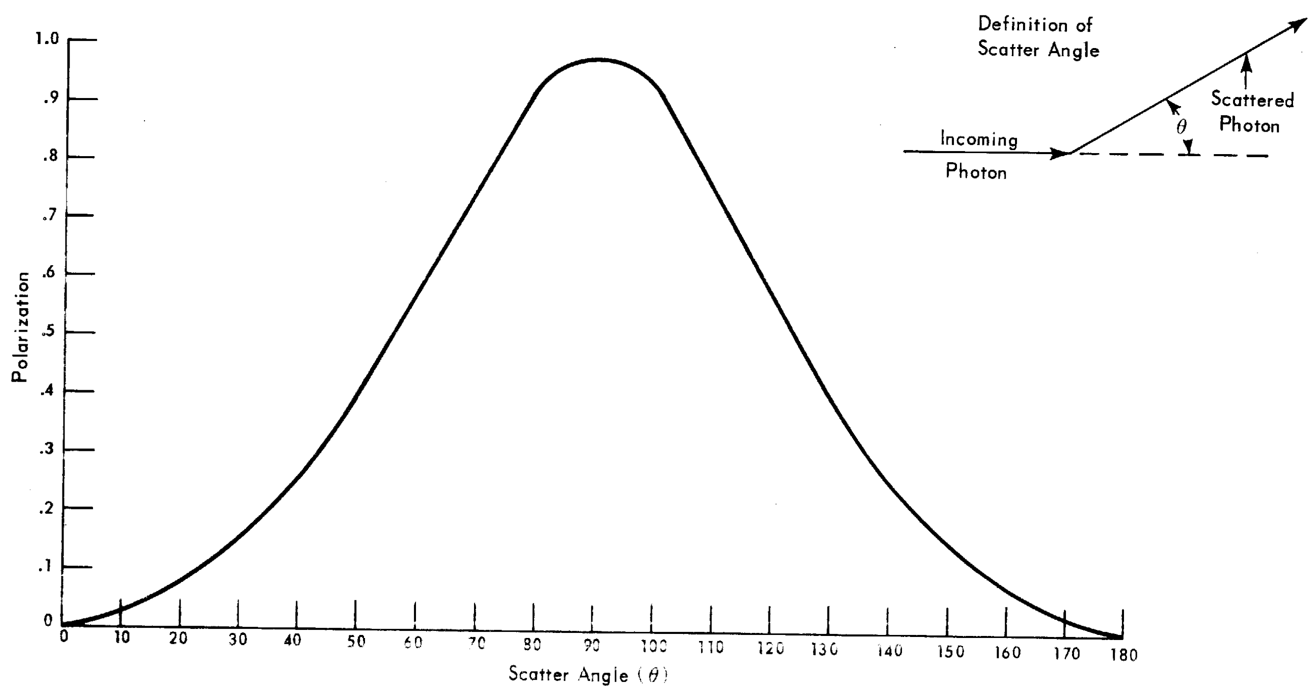

Figure 1. Polarization vs Scatter Angle for Rayleigh Scatter

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two variables are included in the experimental evaluation of the haze penetrating potential of a polarizer.

From the above discussion, it can be inferred that the polarizer will be most effective when looking perpendicularly to the sun on a clear day. Under these conditions, a polarizer should increase both the contrast and the slant range of photographic visibility. On the other hand, on a hazy day, with its associated increase in multiple and aerosol scatter, the polarization of atmospheric scatter is going to be low; and it is doubtful that a significant improvement can be achieved using a polarizer.

In addition to the polarization of haze, some of the scene light is also partially polarized. The principal source of polarized light is specular reflection by dielectric surfaces.

The theory of dielectric surface reflections predicts the polarization as a function of angle of reflection when the dielectric constants of the two materials (e.g. air and water) are known. Again, the polarization is with the E vector perpendicular to the plane of observation. The polarization of reflected light is unity when the angle of incidence is Brewster's angle. The polarization decreases monotonically to zero as the angle of reflectance goes to either zero or 90°. The Brewster's angle θ_B for an air interface is given by

$$\theta_B = \text{arc cot}\,(1/n)$$

where n is the index of refraction for the reflecting medium. The theoretical prediction of polarization as a function of the angle of reflectance is cumbersome and will not be presented here. It may be found in Born and Wolf,[2] but not in an easily used form.

Polarization from dielectric reflections occurs in aerial photography in two important ways. The most important is in the surface reflections from water. Specular reflections of the sun from water will cause serious blooming in the neighborhood of the image of the specular reflection. It also contributes to general flare in the lens since it is a strong source of nonimage-forming light. This specular reflection can be reduced and the contrast of the neighboring imagery greatly enhanced by a polarizer.

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2. Ibid., pp. 43-45

The second way in which polarized specular reflections can affect photographic contrast is when a texture difference exists between an object and its background. For example, the painted lines on a parking lot could have a similar diffuse photographic reflectance to the pavement. However, in the direction in which specular reflections from the sun occur, the lines may be much brighter because of the specular reflections. In this situation, a polarizer oriented to penetrate the atmosphere would actually reduce the contrast of the lines.

All three sources of polarized light (i.e., atmospheric scatter, specular reflections from water, and specular reflections from cultural targets) have been observed in the flight test results.

The typical aerial photographic situation includes both atmospheric scatter and specular reflections. Except when looking into (or away from) the sun, the polarization of light from specular reflections from a horizontal surface will not be in the same direction as that from atmospheric scatter. Consider the case of the sun near the horizon and the target also near the horizon, 90° from the sun. In this case, the plane of observation for atmospheric scatter is horizontal while the plane of observation for specular reflections is vertical. Since the E vectors are perpendicular to the respective planes of observation, they cannot coincide.

In general, the aerial camera is confronted with this combination of optical phenomena. When the dominant source of polarized radiation is specular reflections from water, the most useful orientation of the polarizer is probably to minimize this radiation. On the other hand, when the dominant source is atmospheric scatter, this should be minimized.

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SECTION III

FLIGHT TEST PROGRAM

A. GENERAL

The objective of this program was to determine, qualitatively, the effect of a properly oriented polarizer upon oblique aerial black-and-white photography, in terms of contrast. Thus the variables chosen for the flight test were those representative of the variables in oblique aerial black-and-white photography. These variables were further limited to those which were felt to have an effect upon the difference between imagery photographed with and without a polarizer.

A basis of comparison was the first requirement in the experimental design. Therefore, two cameras were placed on a single mount with their optical axes parallel. One was fitted with a polarizer. Simultaneous pictures were exposed with these cameras.

An important variable was the amount of atmospheric haze present when the flight testing was done. Other than in terms of visibility, we have not found a generally accepted means of classifying atmospheric haze. Since atmospheric classification is beyond the scope of this program, two atmospheric conditions were selected on the basis of visibility and cloud cover. Emphasis was placed in both cases upon selecting atmospheres whose particles provided a significant amount of Rayleigh scatter.

Two types of days were chosen according to the amount of haze in the atmosphere.

The first type of day was clear, with better than 35 miles visibility. The second type of day was denoted as having moderate haze, with between 6 and 10 miles visibility. The thinking was that when there is only a small amount of haze in the atmosphere, it is largely the result of Rayleigh scatter. As the amount of haze in the atmosphere increased, Mie scatter would become more significant.

Another set of variables was chosen to establish the scatter angle and the position of the sun relative to the earth. The specific coordinates chosen to specify the above were: the aircraft heading (relative to the sun), the camera oblique angle, the sun azimuth, and the date and time (for later computation of the zenith position of the sun).

Selection of discrete values for each of these coordinates resulted in a set of situations in the flight program that were representative of a variety of photographic situations.

The two camera oblique angles were 30 and 70 degrees*, the limits of interest in this program. Two sun elevations were also chosen: a low sun and a high sun (at approximately noon). These sun positions were chosen because they represented limiting cases between which other results would fall. However, these two sun positions also provided high polarization of Rayleigh haze for the two camera oblique angles, when looking into the sun. A set of four aircraft headings was chosen to complete this set of variables.

The next variable was altitude. A difference in altitude alters not only the amount of haze one is looking through, but, because of stratification of the atmosphere, it can also vary the type. Two altitudes, 6,000 feet and 12,000 feet, were sufficient for obtaining the results sought in this program.

Two targets were used in this project. One was a CORN edge target, which was chosen as a known input. It was originally hoped that microdensitometer traces of this imagery would provide some quantitative results. The second target was specified as cultural. Two sites were actually photographed in this category, in order to benefit from the local atmospheric conditions. The first was downtown Dayton, Ohio and the second was Lebanon, Ohio. Aerial shots of resolution targets were also made with both cameras to compare their resolution in flight.

The flight test program consisted of four flights, two in clear atmosphere and two in moderate haze. The two flights for each atmosphere included two sun elevations, one with a low sun and one around noon. Thus, the atmosphere and the sun angle combinations formed a four-element matrix as shown.

	Clear Atmosphere	Moderate Haze
Low Sun	Flight 1	Flight 3
Noon	Flight 2	Flight 4

* Oblique angles are measured from the vertical throughout this report.

Each of the flights, in turn, had specific requirements with respect to flight patterns, altitudes, targets, and other aspects. These requirements are described in the following discussion.

All flight directions were specified relative to the sun, as illustrated in Figure 2. The heading flown on a particular leg of the flight was specified by the sun bearing. Thus, the pilot, by considering the camera oblique angle and the sun bearing, determined the leg he should fly in order to satisfy the specifications and to center the target in the format.

Two basic flight patterns were used in this program. The engineering pattern contained only two legs and was used in photographing the CORN edge targets. The purpose of this pattern was to obtain edge target photographs on both the shadow and highlight sides of an earthen dam. This flight pattern is illustrated in Figure 3.

The cultural pattern contained four legs and was used to photograph the cultural target. It incorporated different scatter angles in order to provide a data base for determining the contrast-enhancing capabilities of a polarizer. The cultural flight pattern is illustrated in Figure 4.

The engineering target consisted of two 100-foot CORN edges placed on both sides of Huffman Dam, which runs approximately north and south near Wright-Patterson Air Force Base.

The cultural target was selected to include both highlight and shadow detail. Comparison of contrast enhancement in both highlight and shadow areas is thus possible.

B. CAMERA INSTALLATION

The aircraft camera installation consisted of two KS-67 cameras, equipped with 6-inch lenses, and a closed circuit television camera mounted on a vibration isolated platform. The platform was designed so that the oblique angle (angle between vertical plane and camera axis) could be adjusted from 30° to 70°. Remote monitors for the closed circuit television system were located for convenient viewing by both the pilot and the photographer. The purpose of the closed circuit television was to aid the pilot and photographer in keeping the target within the camera field of view during the exposure run.

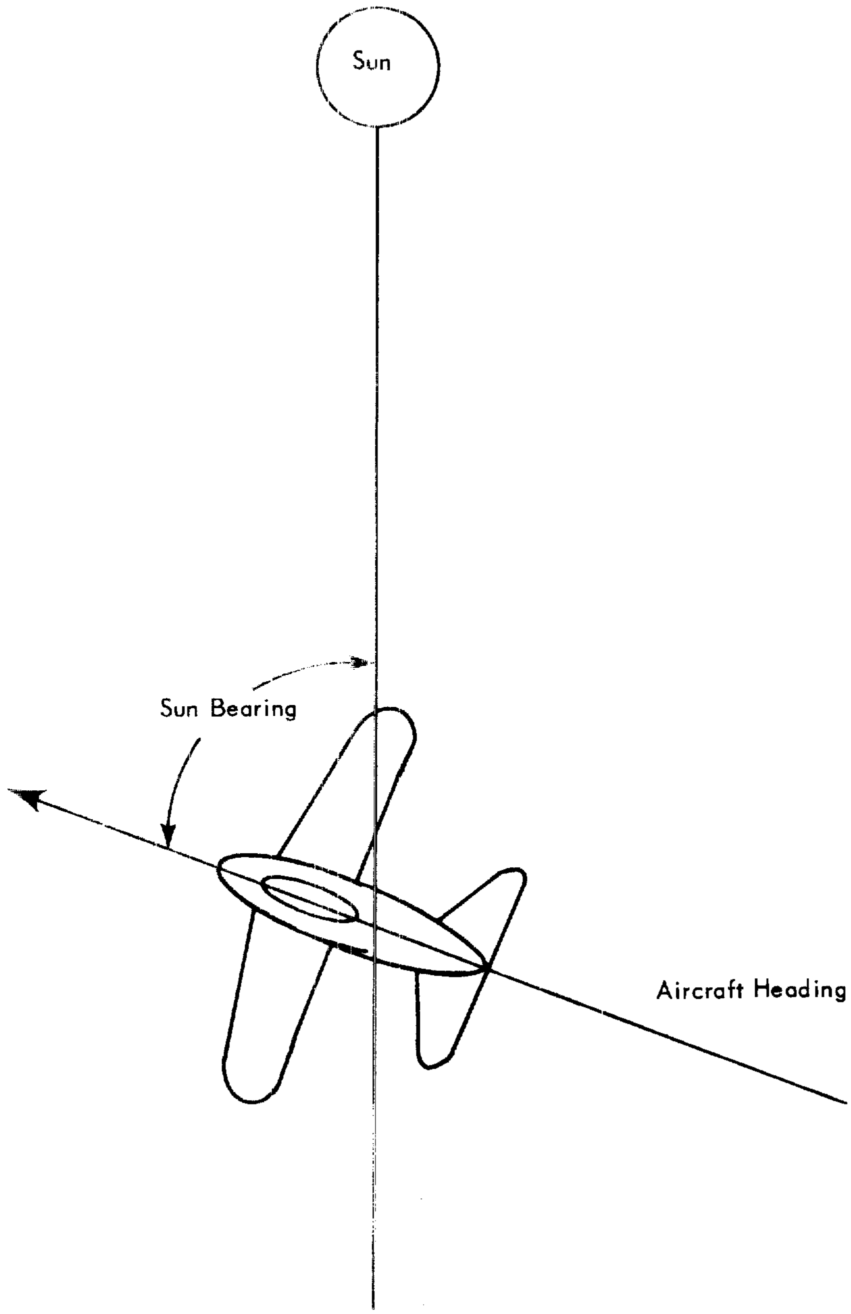


Figure 2. Definition of Sun Bearing

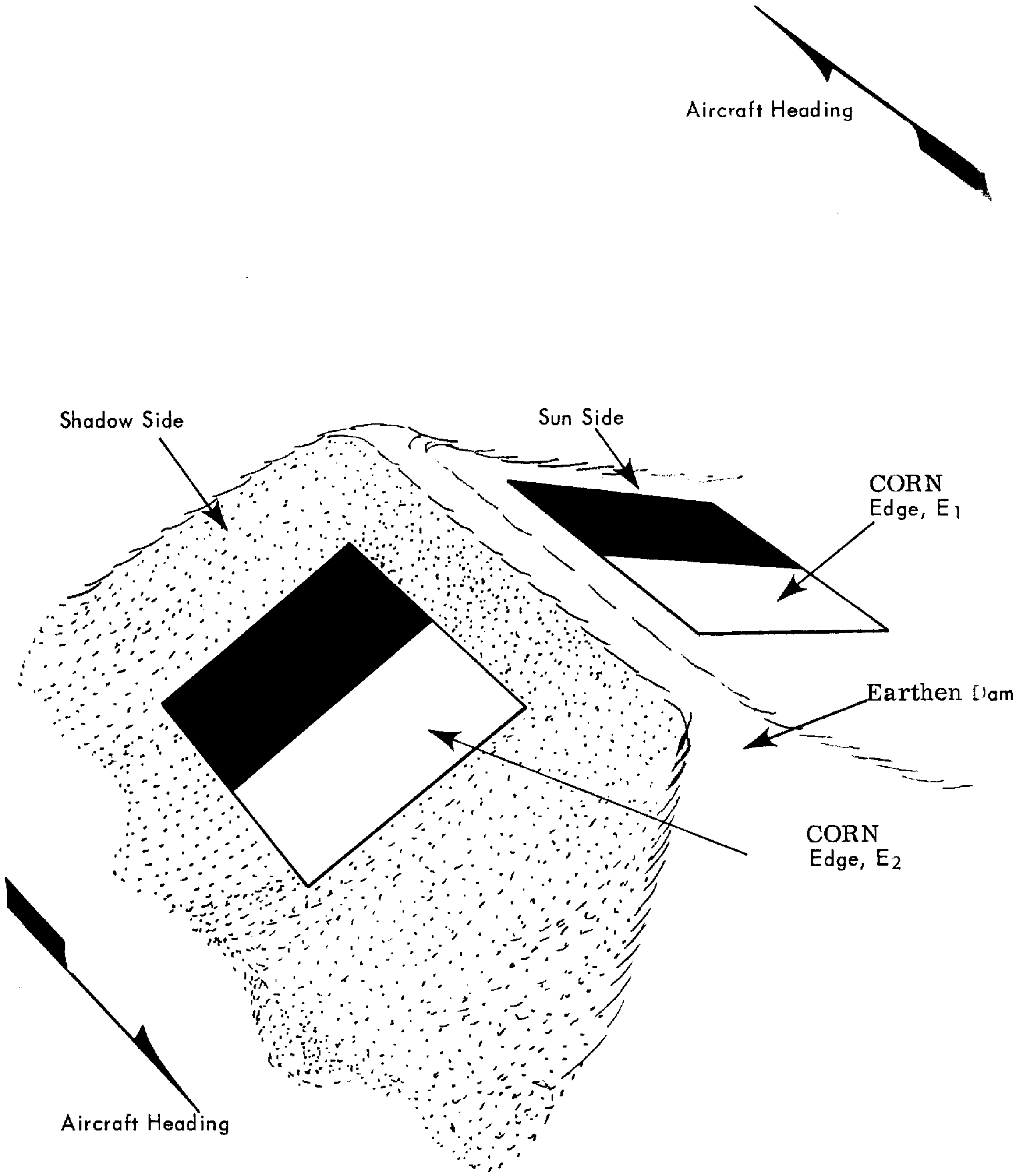
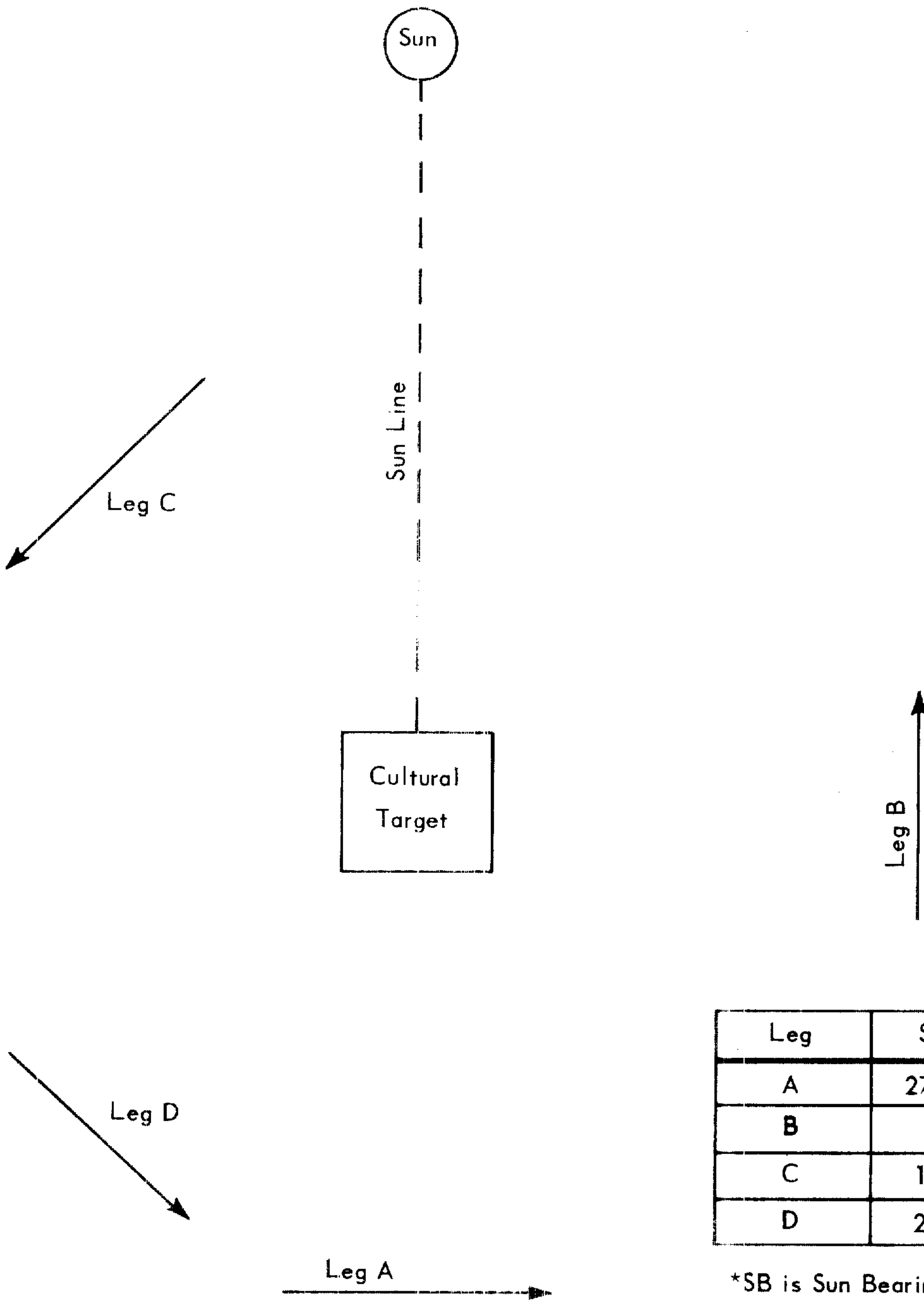


Figure 3. Engineering Flight Pattern



Leg	SB*
A	270°
B	0°
C	135°
D	225°

*SB is Sun Bearing

Figure 4. Cultural Flight Pattern

One of the cameras was fitted with a manually oriented polarizer fabricated by STAT [redacted] The proper direction for the polarizer orientation was determined by the photographer using a polarization axis finder manufactured by [redacted] STAT The axis finder indicates, by a shaded dark line, the axial direction of polarized radiation received from the ground and intervening atmosphere. Before each photographic run, the photographer oriented the polarizer axis perpendicular to the radiation axis.

When there is little polarization of the radiation received by the camera, the black line in the axis finder is difficult to observe. This problem was anticipated. However, when the polarization is this low, the polarizer is not helpful and its orientation has negligible effect upon imagery.

The photography was performed through the port door of the [redacted] STAT STAT [redacted] aircraft. This procedure required that a special door with sliding window be fabricated so that the full range of oblique angles could be obtained without vignetting or mechanical interference. The aircraft installation is shown in Figure 5. The mount, with the KS-67 cameras and the television camera installed, is shown in Figure 6 in the 30° oblique position. The equipment in the 70° oblique position is shown in Figure 7.

C. FLIGHT TESTS

1. Flight 1

Flight 1 represented the low sun and moderate atmospheric haze case. This flight was originally flown on April 16, 1968. Both downtown Dayton and a set of CORN edges were photographed in this flight. Preliminary microdensitometer traces and subsequent analysis indicated that interpretable results could not be obtained in this manner. Subsequent flights were modified, deleting shots of CORN edges.

Further analysis of the imagery from this flight indicated a mismatch in exposures between the two cameras, which did not permit a comparative analysis. Flight 1 was subsequently reflown on April 23, 1968. The flight plan was redesigned to replace the CORN imagery with additional cultural imagery.

Downtown Dayton was again selected on April 23 as the cultural target. The flight took place in the late afternoon to satisfy the low sun requirement of Flight 1.

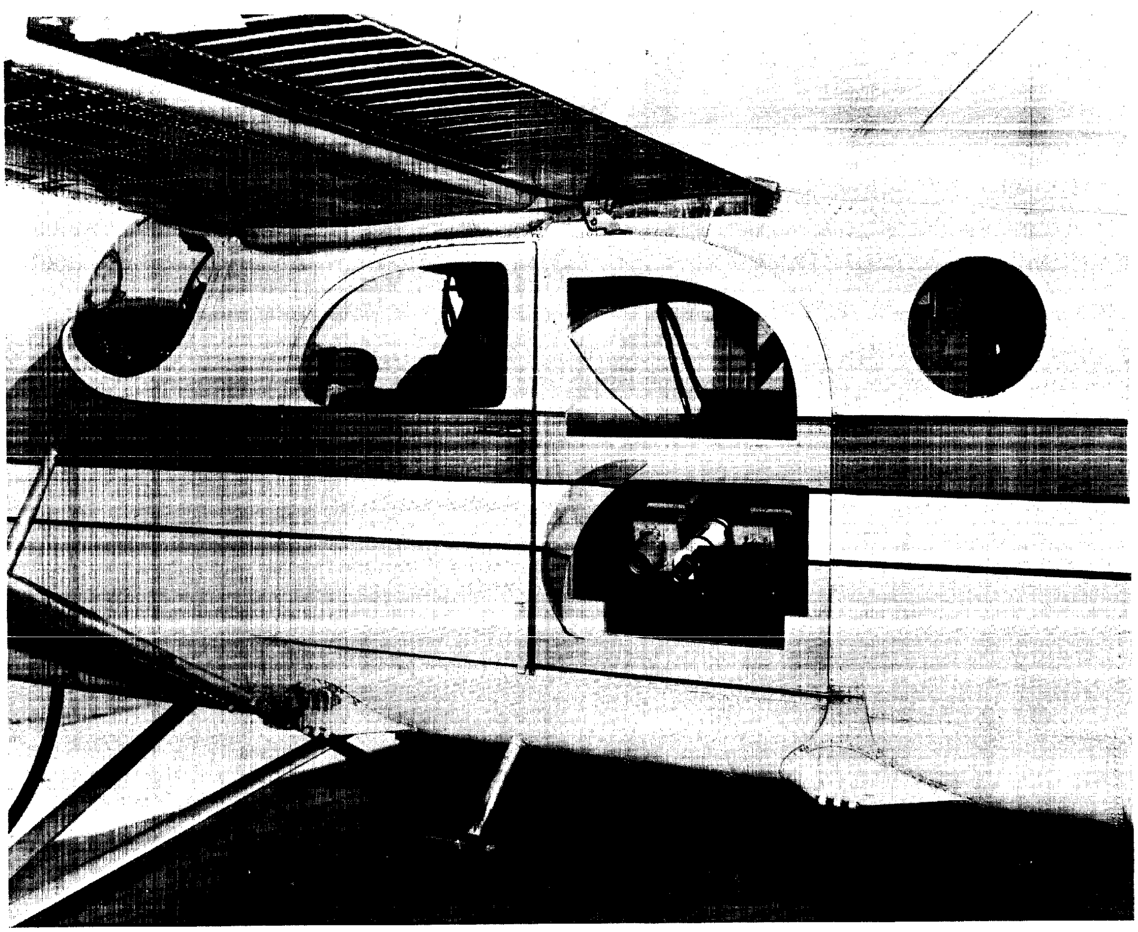


Figure 5. Equipment Installed In Test Aircraft

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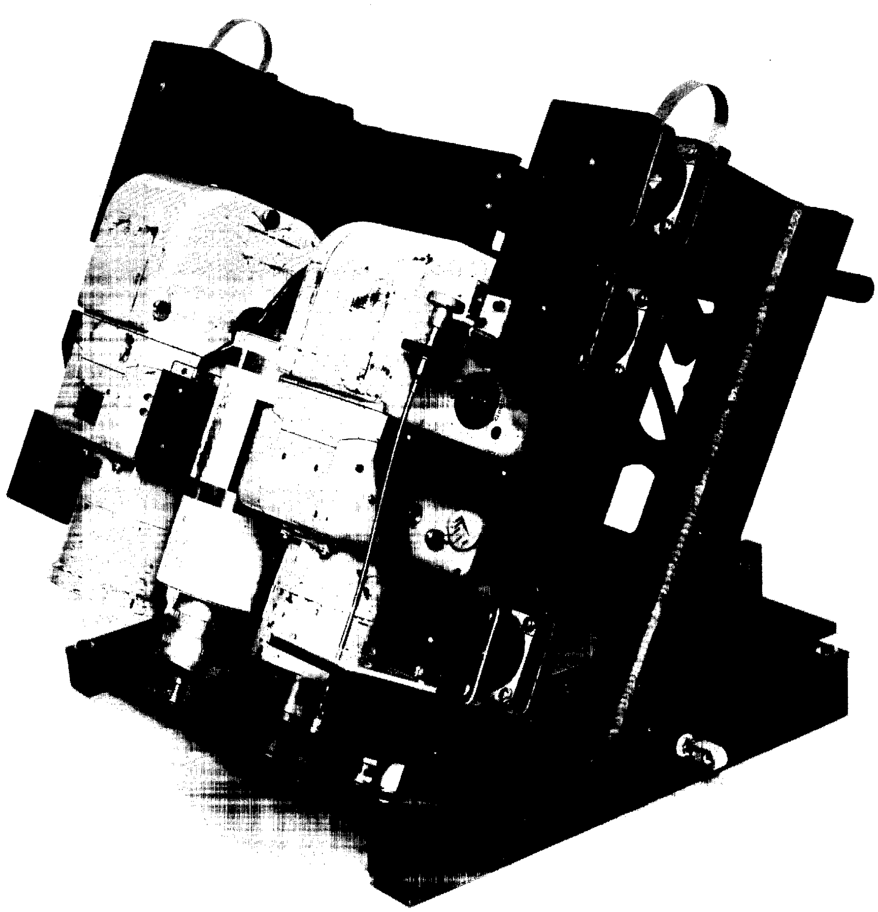

[illegible]
Set At 30° Oblique Angle

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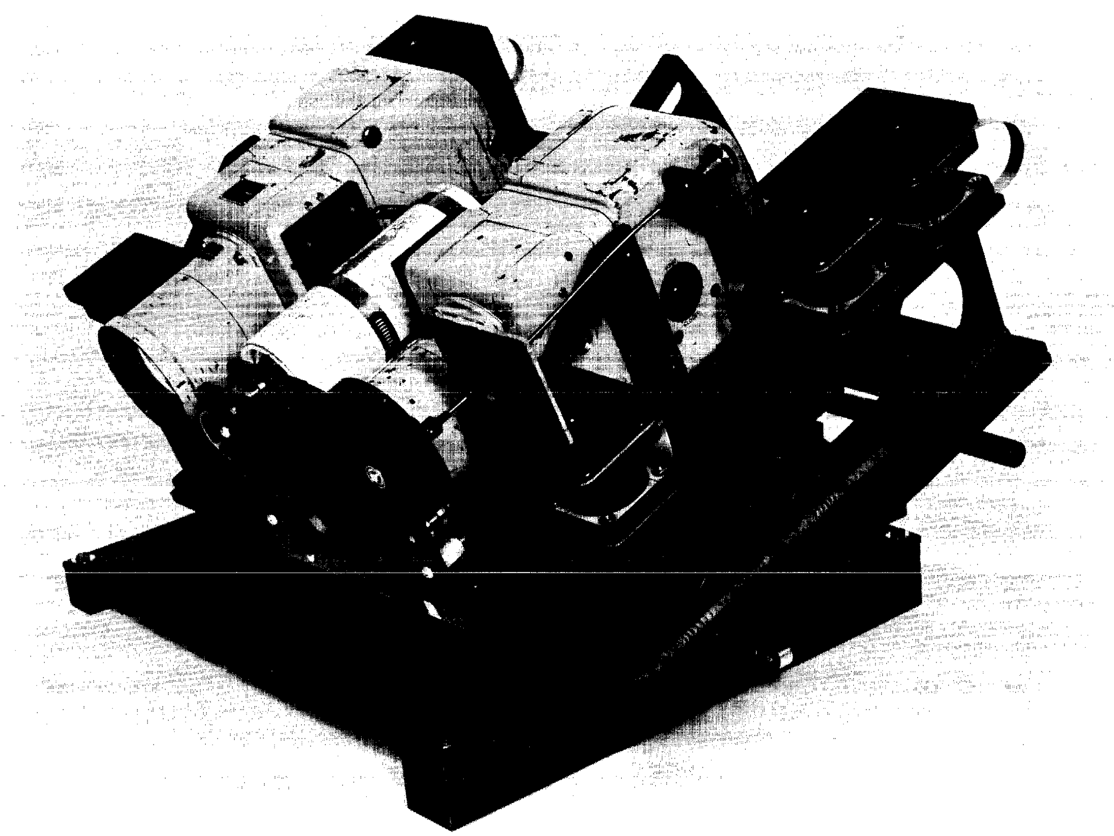

Figure 7. Mount With Equipment Installed,
Set at 70° Oblique Angle

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The atmosphere was moderately hazy with a visibility of about 6 miles.

2. Flight 2

Flight 2 was essentially a duplicate of Flight 1 except that the sun elevation was higher, approximately 62°. The atmosphere for Flight 2 was moderately hazy with about 7 miles visibility. Flight 2 was flown on April 29, 1968, again over Dayton, Ohio. Due to an improper setting of the polarizing filter on one leg of this flight, leg 2-1 had to be reflown on May 1, 1968. The atmospheric conditions were similar on this day to those on April 29. The CORN edges which had originally been scheduled for this flight were deleted and replaced, as in Flight 1, with additional cultural imagery.

3. Flight 3

Flight 3 covered the clear atmosphere, low sun combination. Due to the absence of industrial haze over the area on May 2, 1968, Flight 3 used Lebanon, Ohio as the cultural target. Both 6,000-foot and 12,000-foot altitudes were again flown. The same cultural flight pattern was used.

4. Flight 4

Flight 4 was a duplicate of Flight 3, except that the sun position was near the noon elevation. This flight took place on May 2, 1968, also taking advantage of the unusually clear atmospheric conditions. Lebanon, Ohio was the target, and both 6,000-foot and 12,000-foot shots were included. This was the last flight of this program.

Flight Specification sheets, providing detailed accounts of the flight plans, are included as Figures 8 through 11.

FLIGHT 1

Leg*	Altitude (Feet)	Sun Bearing (Degrees)	Target	Oblique Angle (Degrees)	Leg Designation+
1-1	6,000	270	Dayton	30	A
1-2	6,000	0	Dayton	30	B
1-3	6,000	135	Dayton	30	C
1-4	6,000	225	Dayton	30	D
1-5	6,000	270	Dayton	70	A
1-6	6,000	0	Dayton	70	B
1-7	6,000	135	Dayton	70	C
1-8	6,000	225	Dayton	70	D
1-9	12,000	270	Dayton	30	A
1-10	12,000	0	Dayton	30	B
1-11	12,000	135	Dayton	30	C
1-12	12,000	225	Dayton	30	D
1-13	12,000	270	Dayton	70	A
1-14	12,000	0	Dayton	70	B
1-15	12,000	135	Dayton	70	C
1-16	12,000	225	Dayton	70	D

*The first number corresponds to the flight number. The second number refers to the particular leg within that flight.

+See Figure 4 for diagram of flight pattern.

NOTE

Ten photographs were exposed on each leg.

Figure 8. Flight Specification

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FLIGHT 2

Leg*	Altitude (Feet)	Sun Bearing (Degrees)	Target	Oblique Angle (Degrees)	Leg Designation+
2-1	6,000	270	Dayton	30	A
2-2	6,000	0	Dayton	30	B
2-3	6,000	135	Dayton	30	C
2-4	6,000	225	Dayton	30	D
2-5	6,000	270	Dayton	70	A
2-6	6,000	0	Dayton	70	B
2-7	6,000	135	Dayton	70	C
2-8	6,000	225	Dayton	70	D
2-9	12,000	270	Dayton	30	A
2-10	12,000	0	Dayton	30	B
2-11	12,000	135	Dayton	30	C
2-12	12,000	225	Dayton	30	D
2-13	12,000	270	Dayton	70	A
2-14	12,000	0	Dayton	70	B
2-15	12,000	135	Dayton	70	C
2-16	12,000	225	Dayton	70	D

* The first number corresponds to the flight number. The second number refers to the particular leg within that flight.

+See Figure 4 for diagram of flight pattern.

NOTE

Ten photographs were exposed on each leg.

Figure 9. Flight Specification

FLIGHT 3

Leg*	Altitude (Feet)	Sun Bearing (Degrees)	Target	Oblique Angle (Degrees)	Leg Designation+
3-1	6,000	270	Lebanon	30	A
3-2	6,000	0	Lebanon	30	B
3-3	6,000	135	Lebanon	30	C
3-4	6,000	225	Lebanon	30	D
3-5	6,000	270	Lebanon	70	A
3-6	6,000	0	Lebanon	70	B
3-7	6,000	135	Lebanon	70	C
3-8	6,000	225	Lebanon	70	D
3-9	12,000	270	Lebanon	30	A
3-10	12,000	0	Lebanon	30	B
3-11	12,000	135	Lebanon	30	C
3-12	12,000	225	Lebanon	30	D
3-13	12,000	270	Lebanon	70	A
3-14	12,000	0	Lebanon	70	B
3-15	12,000	135	Lebanon	70	C
3-16	12,000	225	Lebanon	70	D

* The first number corresponds to the flight number. The second number refers to the particular leg within that flight.

+ See Figure 4 for diagram of flight pattern.

NOTE

Ten photographs were exposed on each leg.

Figure 10. Flight Specification

FLIGHT 4

Leg*	Altitude (Feet)	Sun Bearing (Degrees)	Target	Oblique Angle (Degrees)	Leg Designation+
4-1	6,000	270	Lebanon	30	A
4-2	6,000	0	Lebanon	30	B
4-3	6,000	135	Lebanon	30	C
4-4	6,000	225	Lebanon	30	D
4-5	6,000	270	Lebanon	70	A
4-6	6,000	0	Lebanon	70	B
4-7	6,000	135	Lebanon	70	C
4-8	6,000	225	Lebanon	70	D
4-9	12,000	270	Lebanon	30	A
4-10	12,000	0	Lebanon	30	B
4-11	12,000	135	Lebanon	30	C
4-12	12,000	225	Lebanon	30	D
4-13	12,000	270	Lebanon	70	A
4-14	12,000	0	Lebanon	70	B
4-15	12,000	135	Lebanon	70	C
4-16	12,000	225	Lebanon	70	D

* The first number corresponds to the flight number. The second number refers to the particular leg within that flight.

+ See Figure 4 for diagram of flight pattern.

NOTE

Ten photographs were exposed on each leg.

Figure 11. Flight Specification

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SECTION IV

COMMENTARY ON SELECTED PHOTOGRAPHS

A. EXPLANATION

Including all four flights, there were 64 pairs (polarized and nonpolarized) of photographs which had to be analyzed. We attempted to look carefully at every pair and make some statement about the differences observed between the photographs taken with and without the polarizer. In pairs where there were many notable differences, more time was spent examining them. However, we did not attempt to note all of the differences observed. For this reason, a complete set of negatives,which includes a pair of the original negatives from every leg of the flight program,is supplied with this report. These have been mounted and labeled with pertinent data. Location grids for locating points discussed in the text accompany the negatives.

Also included in this section are enlargements made from a few selected negatives, with further commentary on the page facing each print. (See Figures 13 through 20.) These prints were carefully exposed and processed so that each picture taken with the polarizer has received exactly the same printing procedure as its matching picture taken without the polarizer. Thus, no difference in contrast can be attributed to the printing procedure.

Figure 12 illustrates the geometry of the photography and the parameters used to reference the enlargements and original negatives.

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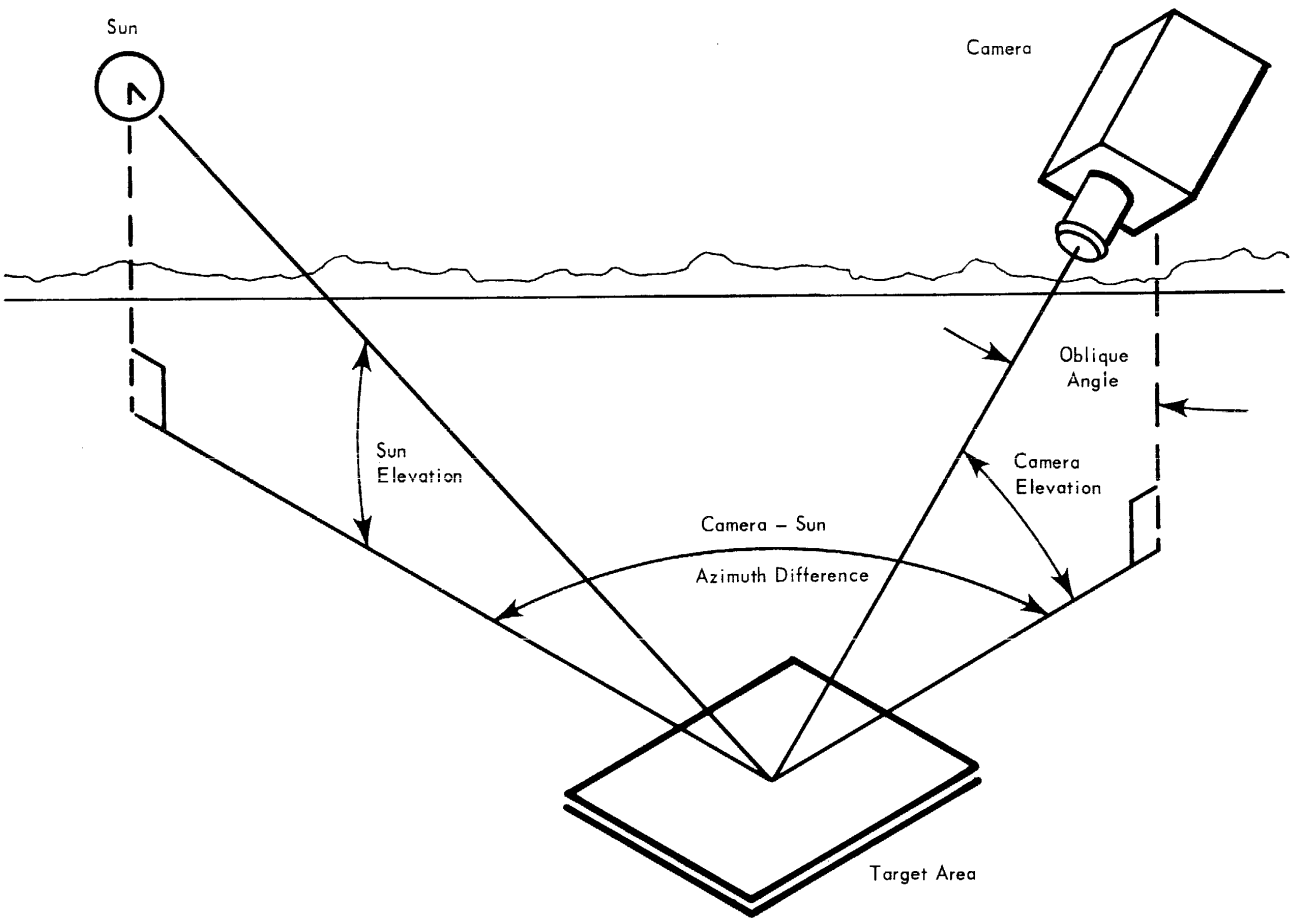
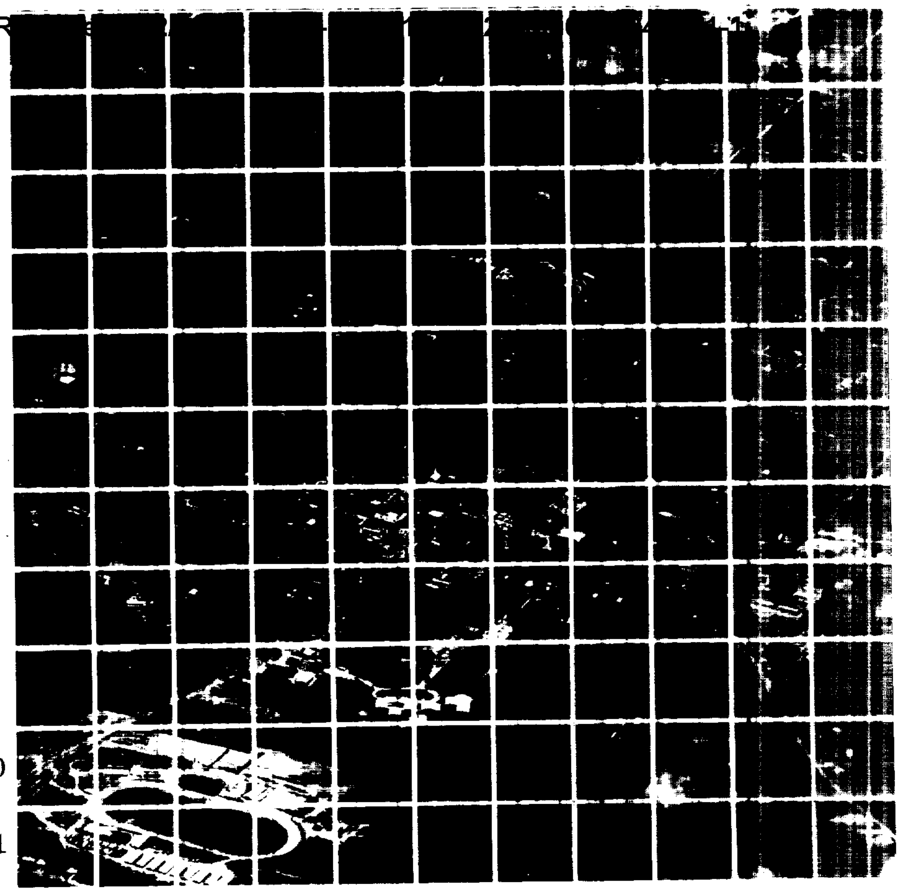


Figure 12. Diagram of Photographic Geometry

POLARIZER



HAZE –	Clear
VISIBILITY –	35 Miles
CAM.–SUN AZIMUTH DIFF. –	180°
ALTITUDE –	12,000 Ft.
OBLIQUE ANGLE –	70°
SUN ELEV. –	65°
TIME –	1245 Hrs.
DATE –	2 May 1968
TGT. AREA –	Lebanon, Ohio
EXP. –	No. 163
SPEED –	1/2000 Sec.
F/STOP –	4.0

NO POLARIZER

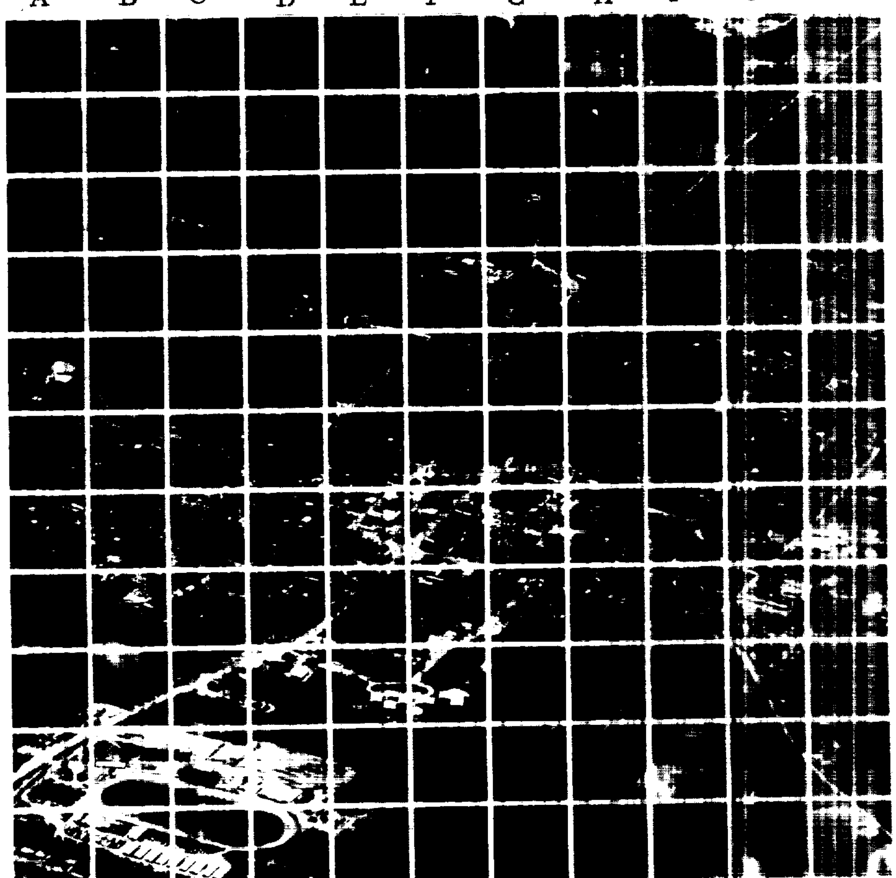


Figure 20. Enlargement No. 8

COMMENTARY ON ENLARGEMENT NO. 7 (Figure 19)

F9 lower left	Contrast enhancement of parking lot in polarized imagery.
B3	Enhancement of specular reflection of cars along road in polarized imagery.
C + D8	Loss of contrast of foliage due to elimination of reflections in polarized imagery. (Note also, however, that the polarized imagery was slightly out of focus.)
General	Contrast enhancement of streets in most of picture in polarized imagery, especially in center of town.

POLARIZER

HAZE -	Clear
VISIBILITY -	35 Miles
CAM.-SUN AZIMUTH DIFF. -	147°
ALTITUDE -	6,000 Ft.
OBLIQUE ANGLE -	70°
SUN ELEV. -	63°
TIME -	1217 Hrs.
DATE -	2 May 1968
TGT. AREA -	Lebanon, Ohio
EXP. -	No. 90
SPEED -	1/2000 Sec.
F/STOP -	4.0

NO POLARIZER

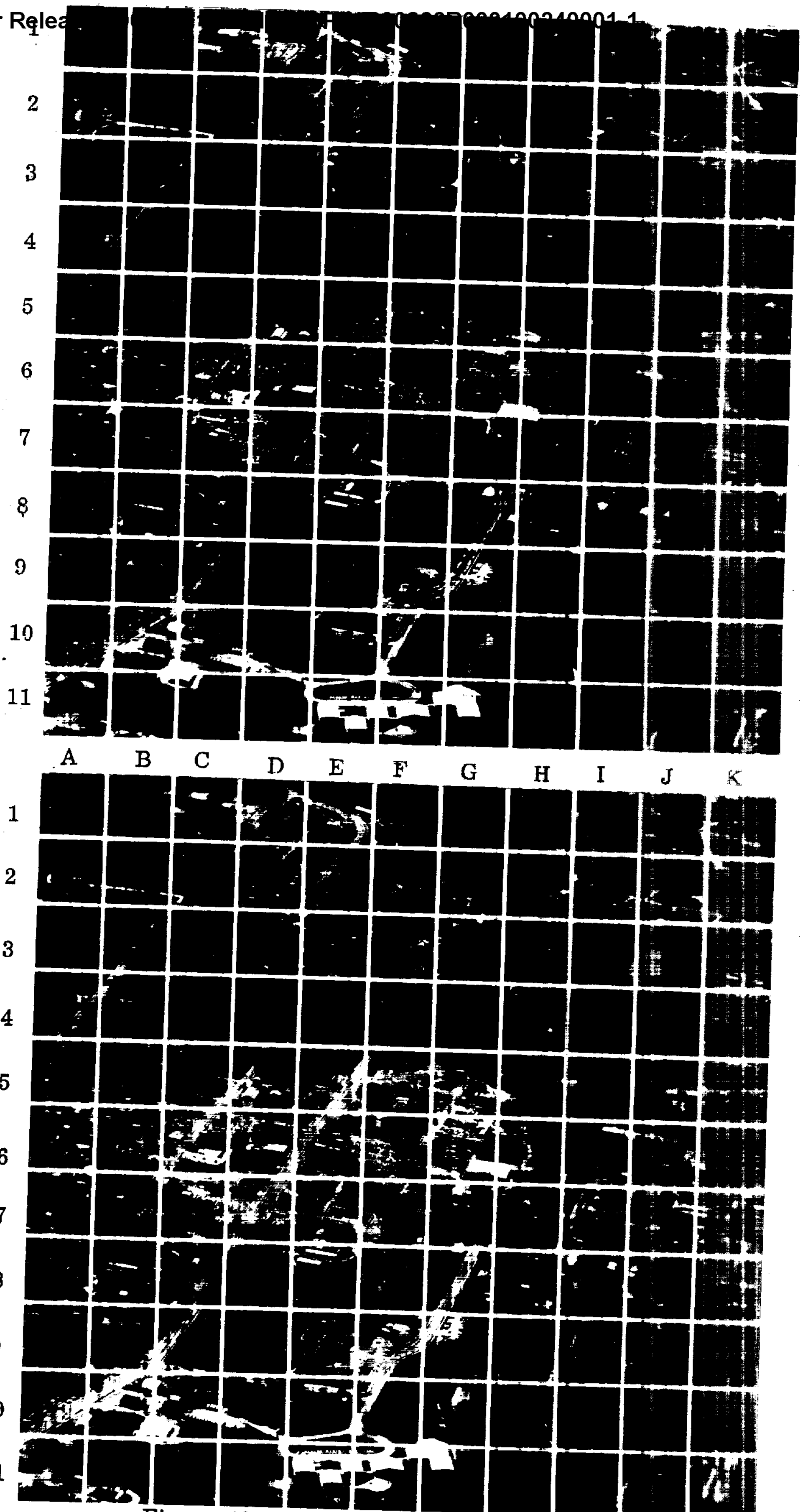
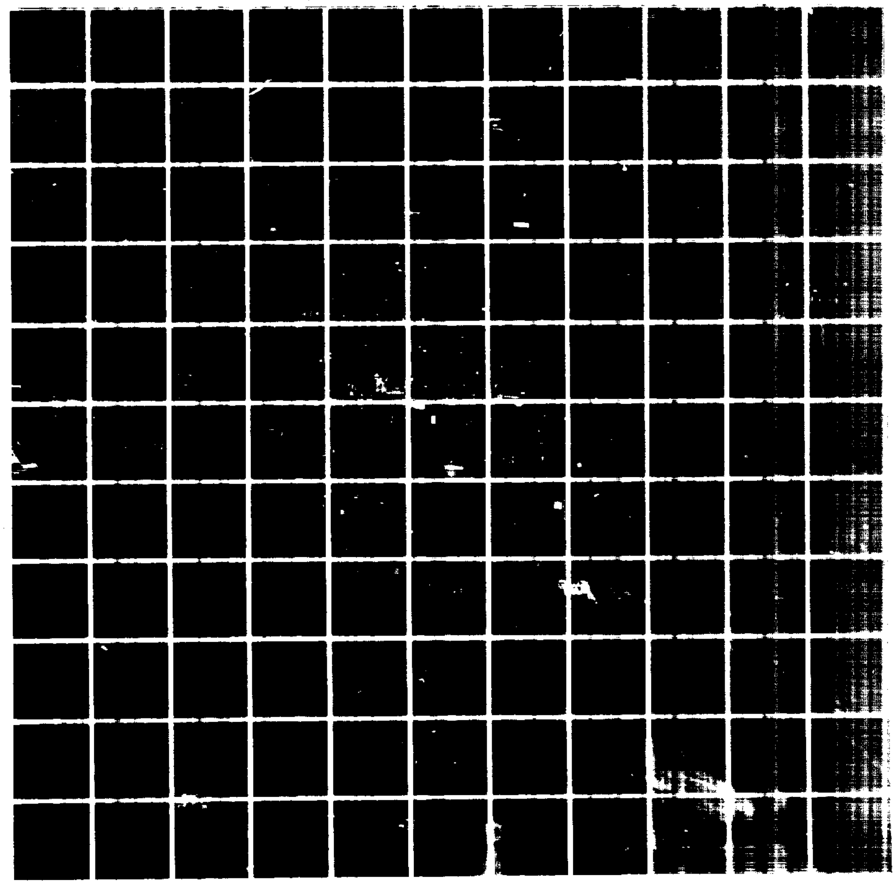


Figure 19. Enlargement No. 7

COMMENTARY ON ENLARGEMENT NO. 6 (Figure 18)

F9 right	Specular reflections from water lying along road is eliminated in polarized imagery.
A + B2 center	Specular reflections from streets are eliminated in the housing development in the polarized imagery.
H8 upper left	Contrast enhancement in polarized imagery gives greater detail to building complex.
H7, H8, I9, J10, K11	Specular reflections from railroad track eliminated in polarized imagery.
F8	Specular reflections from cars and pavement around building are eliminated in polarized imagery.
C6 lower	Specular reflections from pavement and cars on street and parking area are eliminated in polarized imagery.
General	Strong specular reflections from roads and streets are eliminated in polarized imagery, providing detail that is nearly obliterated in nonpolarized imagery. Contrast enhancement provides better detail and definition throughout polarized imagery.

POLARIZER



HAZE – Clear

VISIBILITY – 50+ Miles

CAM.–SUN AZIMUTH DIFF. – 180°

ALTITUDE – 12,000 Ft.

OBLIQUE ANGLE – 70°

SUN ELEV. – 33°

TIME – 0935 Hrs.

DATE – 2 May 1968

TGT. AREA – Lebanon, Ohio

EXP. – No. 204

SPEED – 1/2000 Sec.

F/STOP – 4.0

NO POLARIZER

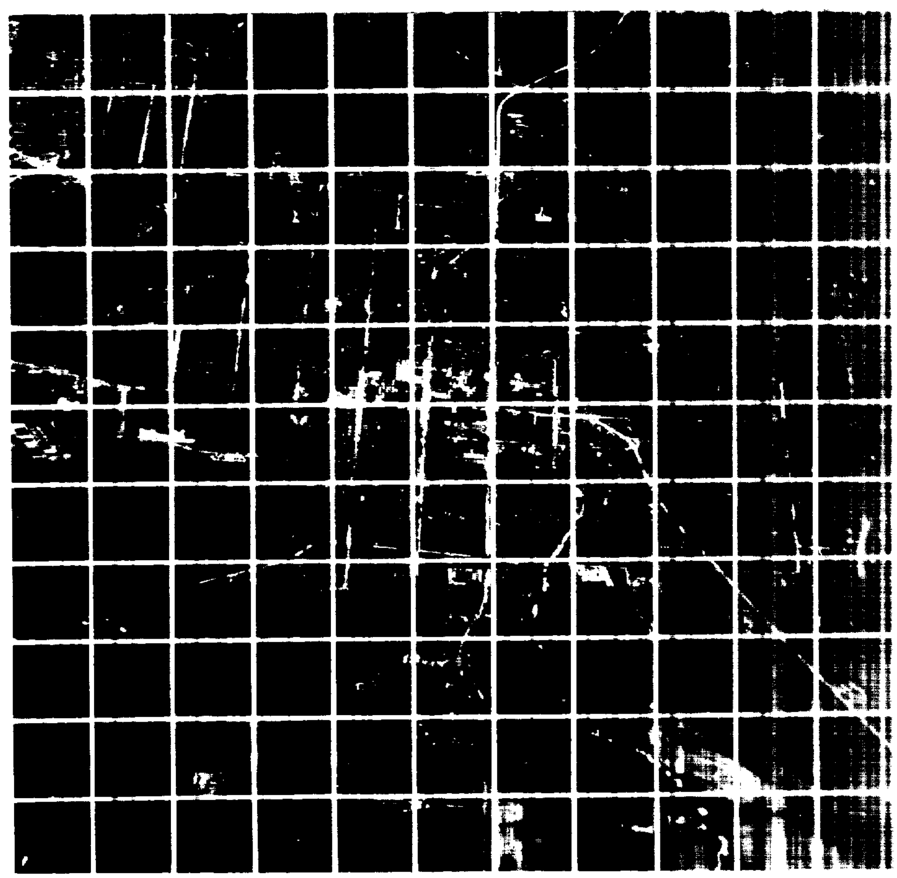


Figure 18. Enlargement No. 6

Approved For Release 2002/10/16 : CIA-RDP71B00822R000100240001-1

COMMENTARY ON ENLARGEMENT NO. 5 (Figure 17)

K2	Lines in tennis court show contrast enhancement in polarized imagery.
J3	Baseball outfield markers show greater detail in polarized imagery.
D7	Contrast enhancement in buildings and street in polarized imagery.
G8	Lines in parking lot show greater detail in polarized imagery.
F5	Lines in the intersection have more contrast in the polarized imagery.
General	Streets in downtown area show a decrease in specular reflections. Overall increase in contrast is evident in polarized imagery.

POLARIZER

HAZE – Clear
VISIBILITY – 50+ Miles
CAM.–SUN AZIMUTH DIFF. – 180°
ALTITUDE – 12,000 Ft.
OBLIQUE ANGLE – 30°
SUN ELEV. – 33°
TIME – 0920 Hrs.
DATE – 2 May 1968
TGT. AREA – Lebanon, Ohio
EXP. – No. 144
SPEED – 1/1000 Sec.
F/STOP – 4.0

NO POLARIZER

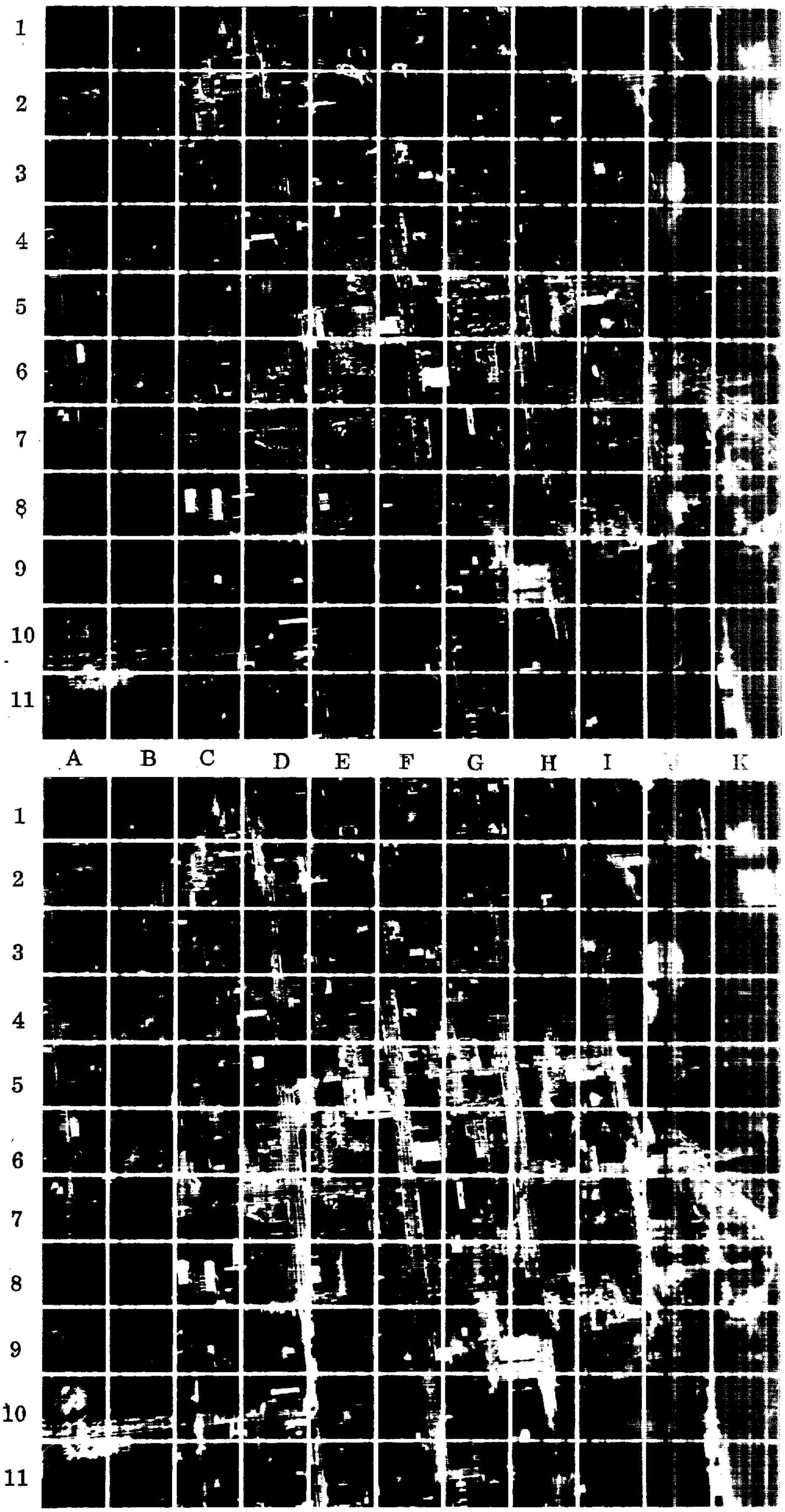


Figure 17. Enlargement No. 5

Approved For Release 2002/10/16 : CIA-RDP71B00822R000100240001-1

COMMENTARY ON ENLARGEMENT NO. 4 (Figure 16)

F8	Reduction of specular reflections from small stream in polarized imagery.
J9 upper left	Reduction of specular reflections from small pond in polarized imagery.
I6	Increase in contrast and detail seen in building complex in polarized imagery.
C3	Specular reflections from street eliminated giving greater detail to cars in polarized imagery.
A + B4	More detail can be seen in cars along side of road in polarized imagery.
F3 left	Cars in street more visible in polarized imagery.
I3, 4, 5, 6	Loss of contrast in polarized imagery due to elimination of specular reflection from railroad tracks.
I6 lower left	Different planes of roof clearly visible only in polarized imagery.
General	Elimination of specular reflections from roads in most of the picture especially in center of town.

Approved For Release 2002/10/16 : CIA-RDP71B00822R000100240001-1

POLARIZER

HAZE – Clear

VISIBILITY – 50+ Miles

CAM.–SUN AZIMUTH DIFF. – 180°

ALTITUDE – 6,000 Ft.

OBLIQUE ANGLE – 70°

SUN ELEV. – 28°

TIME – 0855 Hrs.

DATE – 2 May 1968

TGT. AREA – Lebanon, Ohio

EXP. – No. 71

SPEED – 1/2000 Sec.

F/STOP – 4.0

NO POLARIZER

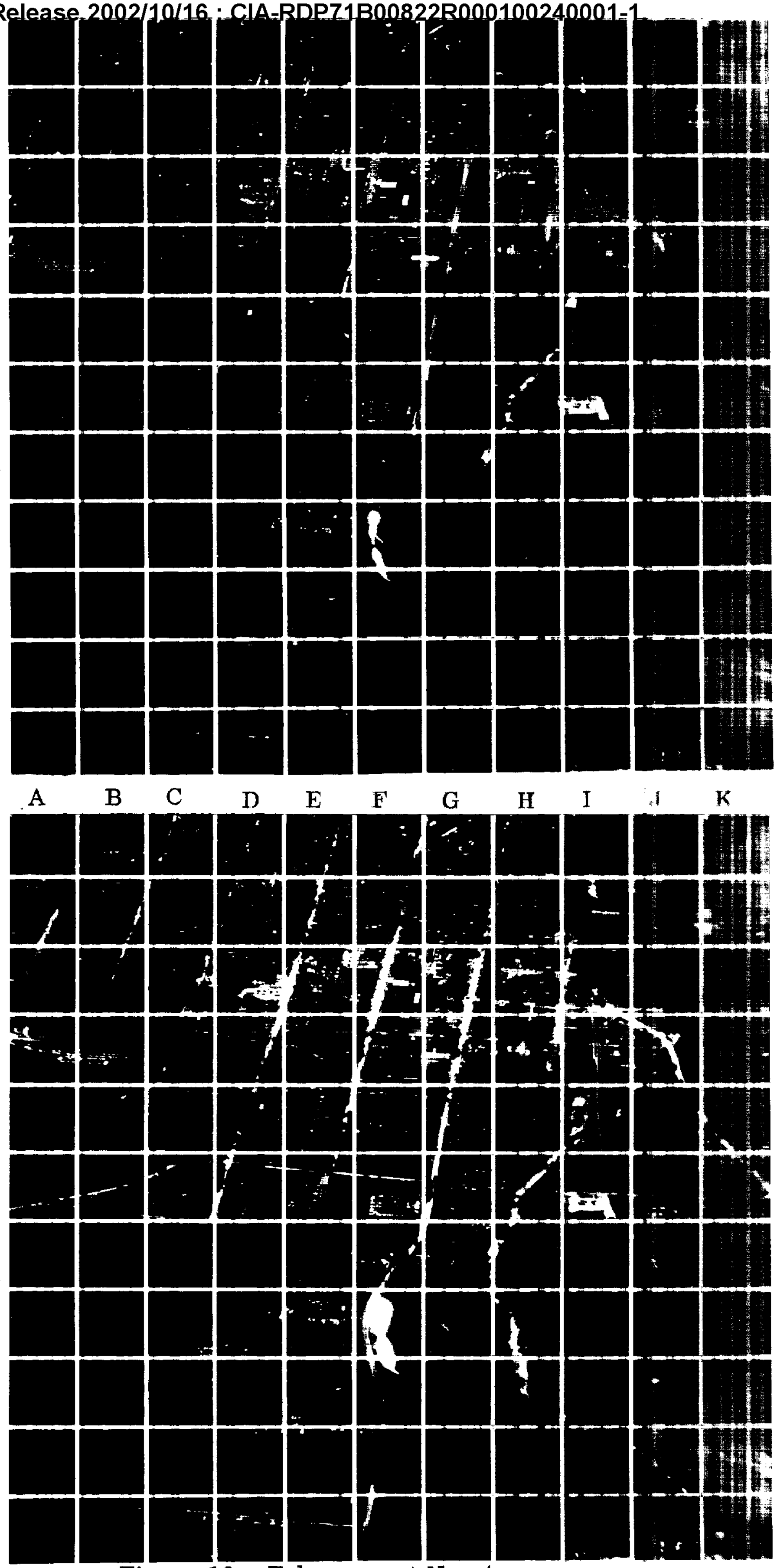
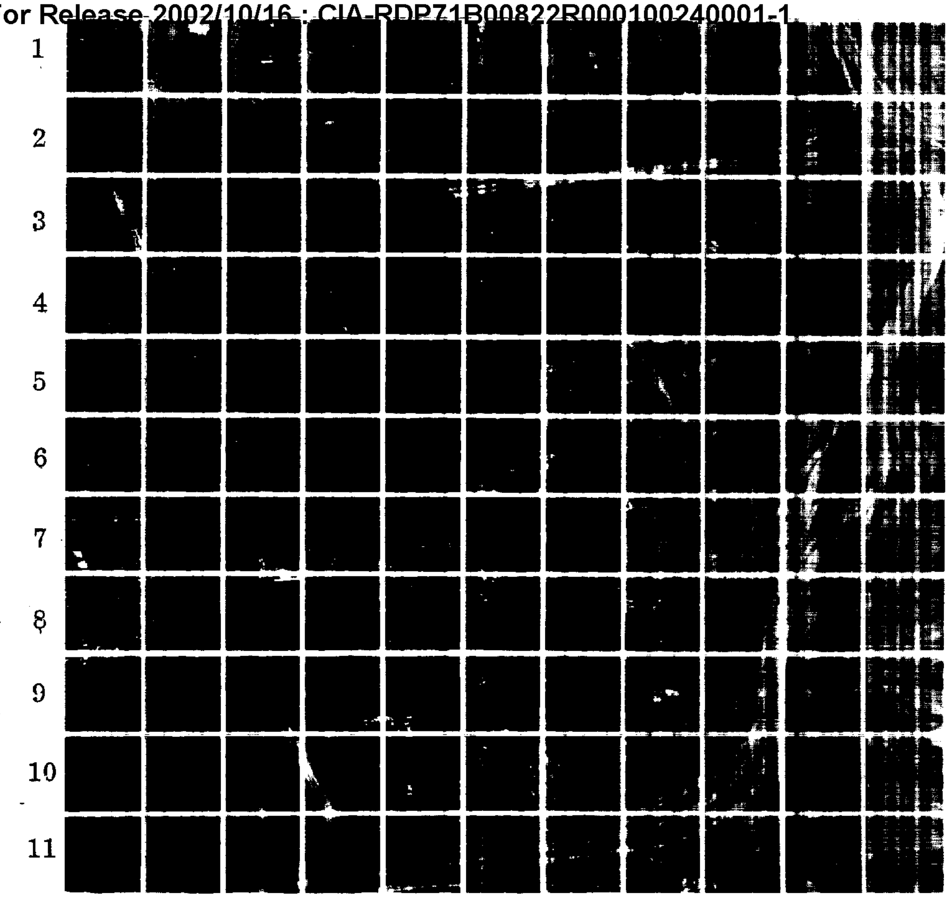


Figure 16. Enlargement No. 4

COMMENTARY ON ENLARGEMENT NO. 3 (Figure 15)

H7	Contrast increase in windows of building in upper left corner of polarized imagery.
A + B6, 7, 8	Lines in streets appear to increase in contrast in polarized imagery.
A8	Cars in parking lot show a definite contrast increase in the polarized imagery.
G6 lower left	Windows of building have increased in contrast in polarized imagery.
E, F, G9 +10	Contrast increases in automobiles in polarized imagery.
General	Decrease of specular reflections from streets and river throughout polarized imagery. Also a general contrast improvement is present in the polarized imagery.

POLARIZER



HAZE –	Moderate
VISIBILITY –	7 Miles
CAM.-SUN AZIMUTH DIFF. –	180°
ALTITUDE –	12,000 Ft.
OBLIQUE ANGLE –	70°
SUN ELEV. –	62°
TIME –	1341 Hrs.
DATE –	29 April 1968
TGT. AREA –	Dayton, Ohio
EXP. –	No. 208
SPEED –	1/2000 Sec.
F/STOP –	4.0

NO POLARIZER

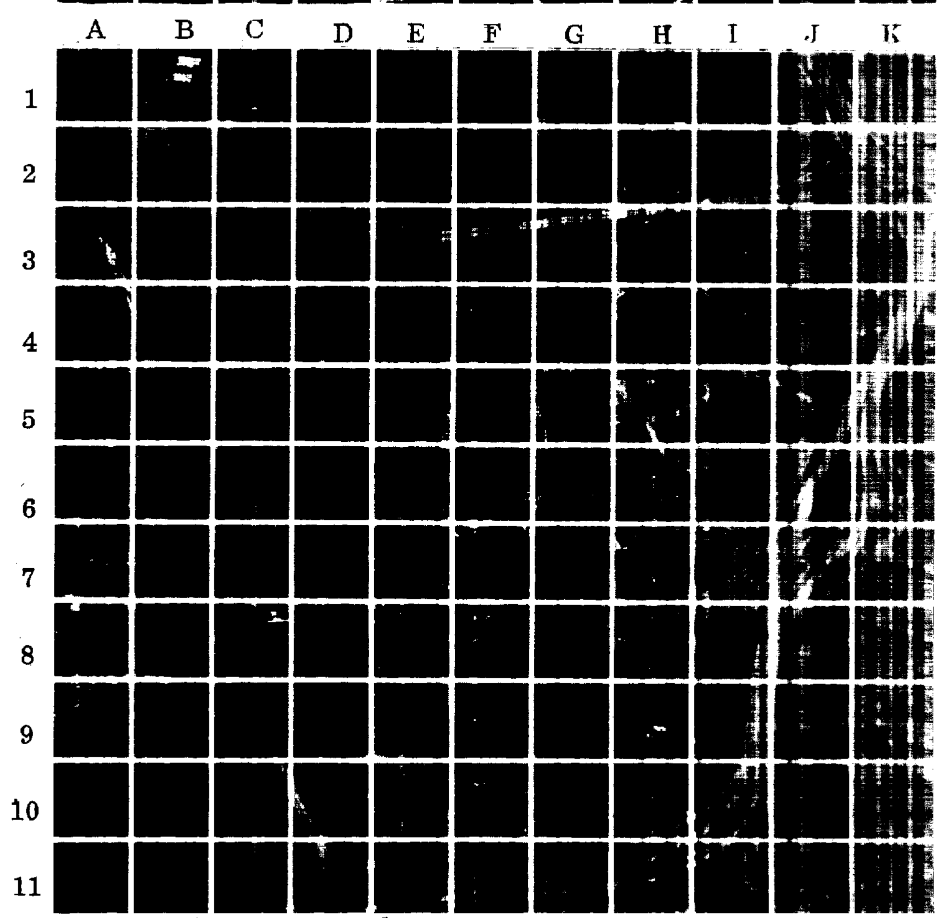


Figure 15. Enlargement No. 3

COMMENTARY ON ENLARGEMENT NO. 2 (Figure 14)

B2	Increase in contrast of windows on shaded side of building in polarized imagery.
F6	Polarized imagery shows more contrast in windows of building in deep shadows.
J + K2	Elimination of slight specular reflection from river in polarized imagery.
C3	Polarized imagery shows more detail of the shadows on roof of large building.
D + E3	Increase in contrast of street in shadow of building in polarized imagery.
General	Slight overall increase in contrast in polarized imagery. Shadow areas of polarized imagery show more detail. (Right side of nonpolarized print appears slightly out of focus.)

POLARIZER

HAZE – Moderate

VISIBILITY – 6 Miles

CAM.–SUN AZIMUTH DIFF. – 175°

ALTITUDE – 12,000 Ft.

OBLIQUE ANGLE – 30°

SUN ELEV. – 25°

TIME – 1759 Hrs.

DATE – 23 April 1968

TGT. AREA – Dayton, Ohio

EXP. – No. 141

SPEED – 1/1000 Sec.

F/STOP – 4.0

NO POLARIZER

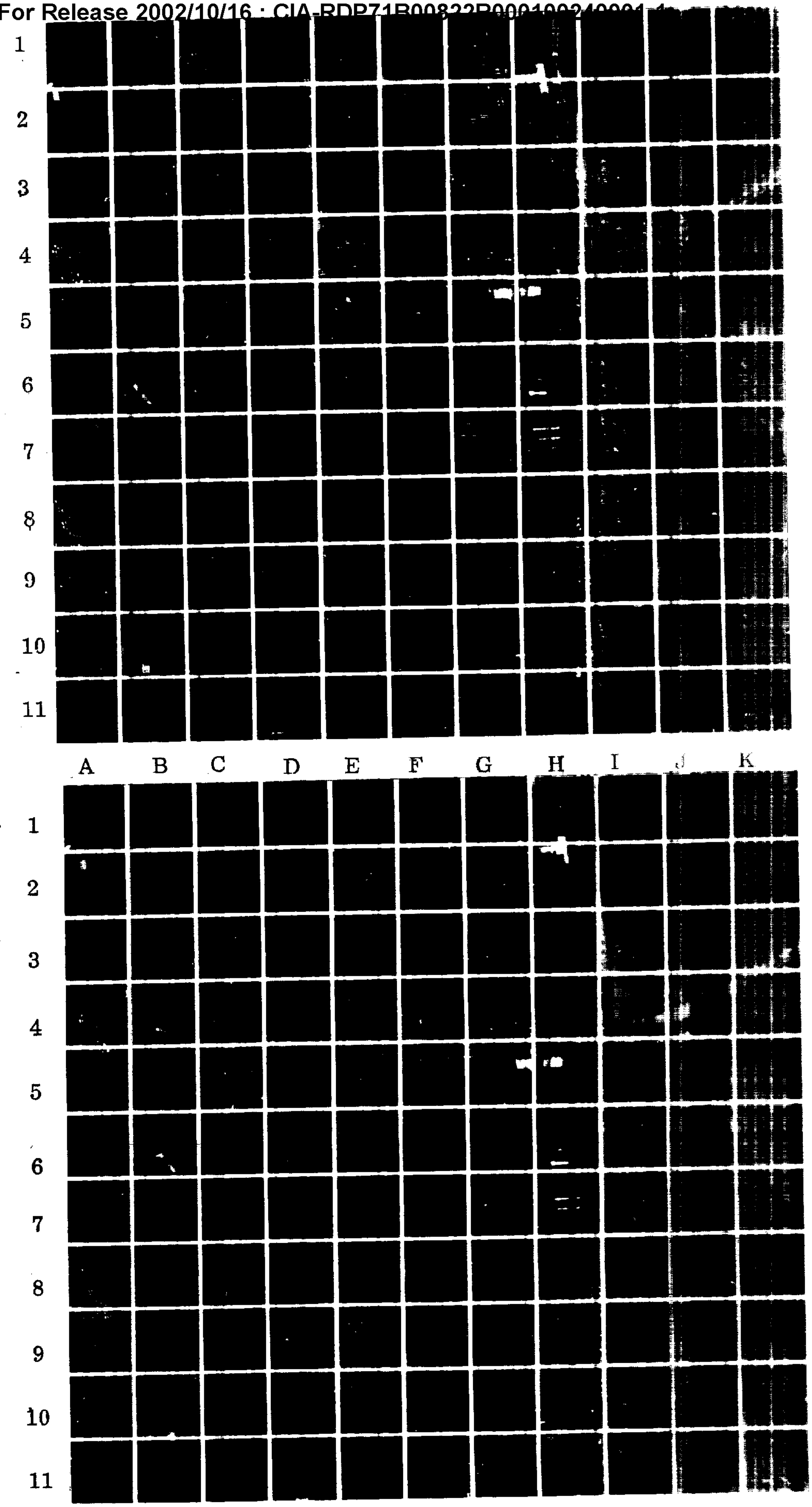


Figure 14. Enlargement No. 2

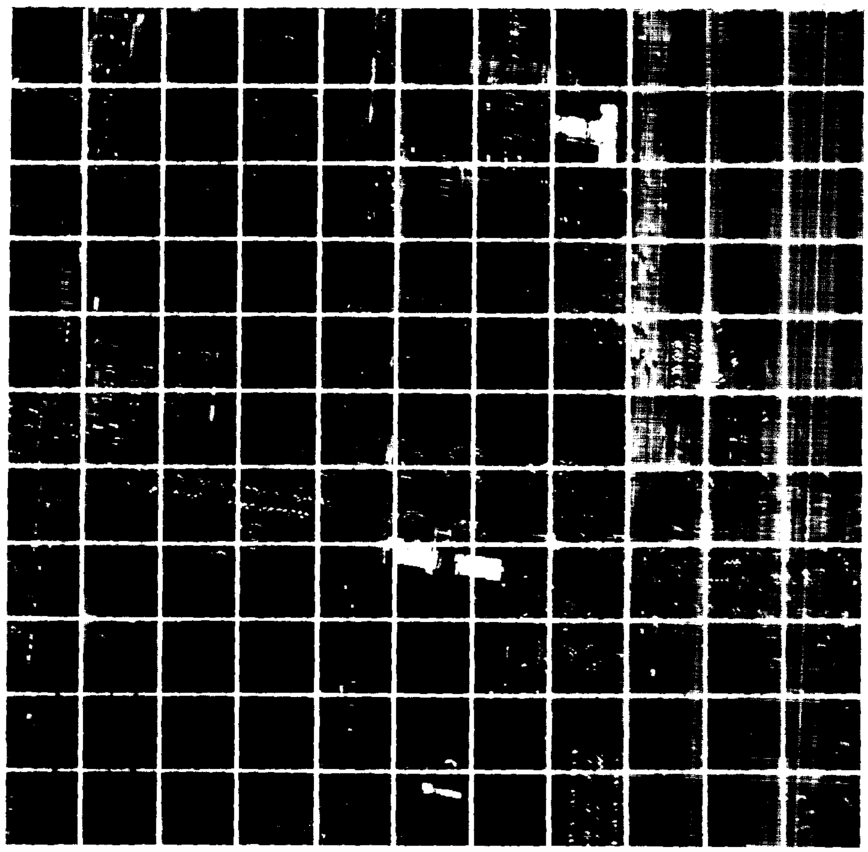
B. SELECTED ENLARGEMENTS AND COMMENTARY

COMMENTARY ON ENLARGEMENT NO. 1 (Figure 13)

B, C, D9 lower	Windows in building are more visible in the polarized imagery.
C1	Elimination of reflections from wet roof in polarized imagery.
El lower left	Elimination of reflections from wet roof reveals an object in polarized imagery, obscured in nonpolarized imagery.
E9 center	Contrast increase of polarized imagery enhances the visibility of white dotted line on street, particularly in the shadow of the building on right of street.
J + K7	Detailed structure of railing along far side of road revealed only in polarized imagery.
C2	Parking lot lines are more visible in polarized imagery.

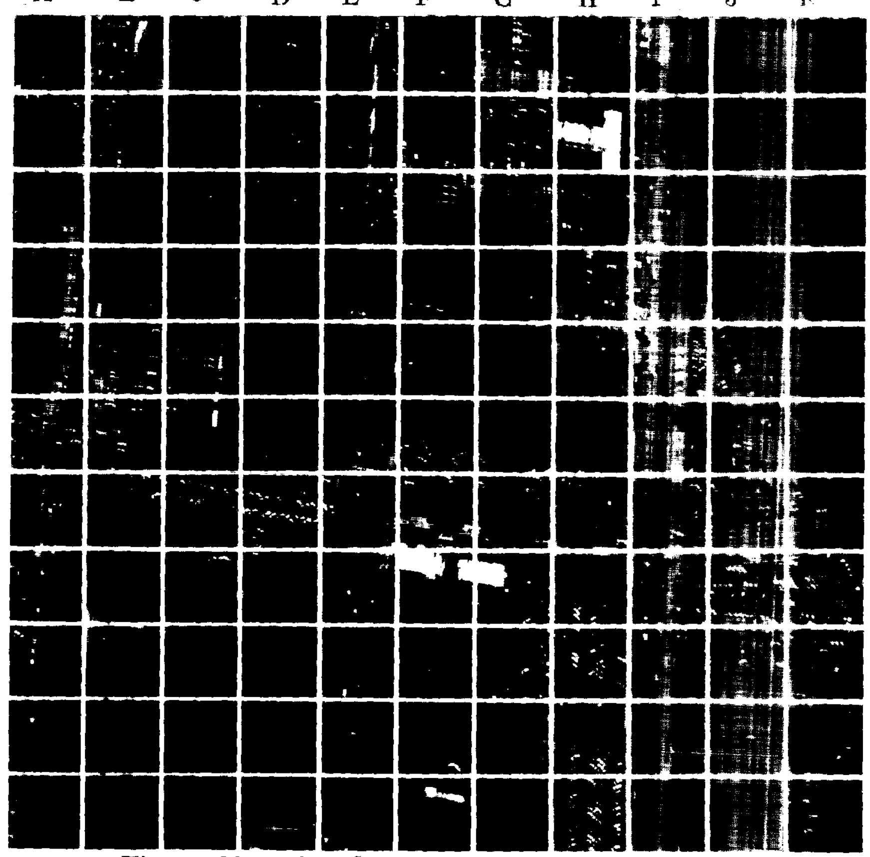
POLARIZER

1 2 3 4 5 6 7 8 9 10 11



A B C D E F G H I J K

1 2 3 4 5 6 7 8 9 10 11



NO POLARIZER

HAZE –	Moderate
VISIBILITY –	6 Miles
CAM.–SUN AZIMUTH DIFF. –	180°
ALTITUDE –	6,000 Ft.
OBLIQUE ANGLE –	30°
SUN ELEV. –	30°
TIME –	1726 Hours
DATE –	23 April 1968
TGT. AREA –	Dayton, Ohio
EXP. –	No. 3
SPEED –	1/500 Sec.
F/STOP –	4.0

Figure No. 13 Enlargement No. 1

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COMMENTARY ON ENLARGEMENT NO. 8 (Figure 20)

E, F, G7	Center of town shows more detail due to contrast increase in polarized imagery.
General	Overall increase in contrast and detail apparent throughout polarized imagery. Particular contrast enhancement in area surrounding the race track in the lower left portion of the prints. Attention should also be given to the upper portion of the photographs where the exposures are more closely matched. In this area the polarized imagery still demonstrates a marked increase in contrast.

C. COMMENTARY ON NEGATIVES

NOTE

It is imperative that the set of negatives supplied with this report be used with this commentary in order to obtain maximum information on the testing.

Flight 1

Leg 1-1 Exposures 1-18

E5 + E4 lower half	Difference due to light reflected from wet roof.
J6 lower left	Difference due to specular reflections from river.
D4 center right	Difference due to specular reflections from roof.
F5 center left	Notice car in no parking zone, printed lines on street visible in polarized imagery, barely visible in other.
G6 center left	Billboard and roof of building have increased contrast in polarized imagery.
E3 lower	Rooftop parking lot lines enhanced in polarized imagery.
D8	Large building with water tower on top shows increased contrast in polarized imagery.
General	Reflections from streets is reduced throughout picture in polarized imagery. See also Enlargement No. 1, Figure 13.

Leg 1-2 Exposures 19-33

A4 - K4	Slight increase in contrast in streets in polarized imagery.

Leg 1-3 Exposures 34-49

General	No significant differences were noted.

Leg 1-4 Exposures 50-66

G7	Windows in large building are more prominent in polarized imagery.
General	A very slight contrast enhancement is evident in the

	polarized imagery when the pictures are viewed in their entirety.
Leg 1-5 Exposures 67-86	
Upper and right	Roads in the polarized imagery have a loss of contrast with their surrounds due to reflections.
Leg 1-6 Exposures 87-101	
G4	Apparent increase of contrast and detail in large building and surrounding area in polarized imagery.
E + F, 9 + 10	Contrast enhancement of highway and highway construction in polarized imagery.
B, C, D, E 6	Slight increase in contrast in building complex in polarized imagery.
Leg 1-7 Exposures 102-115	
General	Polarized imagery appears slightly out of focus, suggesting slight malfunction in camera, as this was not noted in other imagery.
Leg 1-8 Exposures 116-128	
General	Very slight overall increase in contrast in polarized imagery.
Leg 1-9 Exposures 129-141	
H1	Reduction of specular reflections from roof of building in polarized imagery.
D4	Reduction of specular reflections from roof of building in polarized imagery.
G6	Contrast increase of street intersection in shadow of building in polarized imagery.
E8	Increased detail in roadway in polarized imagery.
J8	Windows in building are more prominent in polarized imagery.
H3	Contrast enhancement in polarized imagery makes the parking levels in circular parking lot ramp more visible.

H11	Polarized imagery shows elimination of specular reflections on roof of building.
F3	Windows in building are more prominent in polarized imagery.
General	There are many more examples of contrast increase and reflection suppression in the polarized imagery. See also the Enlargement No. 2, Figure 14.

Leg 1-10 Exposures 142-161

F3	Contrast increase in windows on shadow side of building in polarized imagery.
H4	Increased detail, sidewalk in shadow around building in polarized imagery.
General	Overall increase of contrast and detail in polarized imagery.

Leg 1-11 Exposures 162-177

General	No significant differences were noted.

Leg 1-12 Exposures 178-195

H4	Increased contrast in the windows of building and in levels of parking garage in polarized imagery.
G4	Increased contrast in the windows of building in polarized imagery.

Leg 1-13 Exposures 196-215

General	General loss of contrast in polarized imagery due to reduction of specular reflections such as river and roads.

Leg 1-14 Exposures 216-229

E6	Slight contrast increase in windows of building in polarized imagery.
General	No significant differences were noted.

Leg 1-15 Exposures 230-248

General	No significant differences were noted.

Leg 1-16 Exposures 249-269

General	No significant differences were noted.

Flight 2

Leg 2-1 Exposures 1-16	
General	Slight overall increase in contrast in polarized imagery.
Leg 2-2 Exposures 17-33	
General	No significant differences were noted.
Leg 2-3 Exposures 34-49	
General	No significant differences were noted.
Leg 2-4 Exposures 50-67	
General	No significant differences were noted.
Leg 2-5 Exposures 68-82	
General	Polarized imagery shows decreased reflections from streets and river throughout. Polarized imagery also shows an overall increase in contrast.
Leg 2-6 Exposures 83-98	
General	No significant differences were noted.
Leg 2-7 Exposures 99-116	
H6 lower center	Dark object appears in polarized imagery but not in nonpolarized imagery.
General	Polarized imagery shows overall slight contrast increase.
Leg 2-8 Exposures 117-132	
General	Polarized imagery shows reduction of reflections from river and streets.
Leg 2-9 Exposures 133-149	
E9 lower, F10 upper	Specular reflections are decreased in polarized imagery.
Leg 2-10 Exposures 150-164	
General	No significant differences were noted.
Leg 2-11 Exposures 165-180	
General	No significant differences were noted.
Leg 2-12 Exposures 181-194	
General	No significant differences were noted.

Leg 2-13 Exposures 195-214

E4 lower center	Specular type reflections from circular shaped object with line through it are decreased, lowering contrast in the polarized imagery.
D5 rt. center and E5 center left	Contrast loss with polarized imagery in stadium due to elimination of specular reflections.
B + C11 upper	Light area with long parallel dark lines (just below river) is more visible through smoke in polarized imagery than in nonpolarized imagery.
G7 upper right	Object on bridge appears only in polarized imagery.
General	Decrease of specular reflections from streets and river throughout polarized imagery. Also a general contrast improvement is present in the polarized imagery, especially in the downtown area. See also Enlargement No. 3, Figure 15.

Leg 2-14 Exposures 215-232

General	No significant differences were noted.

Leg 2-15 Exposures 233-248

General	No significant differences were noted.

Leg 2-16 Exposures 249-266

General	Elimination of specular reflections from river in polarized imagery. Slight overall increase in contrast in polarized imagery.

<u>Flight 3</u>

Leg 3-1 Exposures 1-16

C + D9	Reduction of reflection from roofs of buildings is reduced in polarized imagery.
B4	Reduction of specular reflections from road in front of building in polarized imagery.
General	General reduction of road reflections in polarized imagery.

Leg 3-2 Exposures 17-32	
F + G5	Reduction of reflection from building roof (the half in direct sunlight) in polarized imagery.
Leg 3-3 Exposures 33-48	
General	No significant differences were noted.
Leg 3-4 Exposures 49-68	
D3	Windows in shadow side of building have more contrast in the polarized imagery.
F3	Specular reflection from wet roof of building in lower left corner are reduced in the polarized imagery.
G2	Slight contrast increase visible in roads in polarized imagery.
F3	Slight contrast increase in intersection in polarized imagery.
Leg 3-5 Exposures 69-83	
G7, 8, 9	Specular reflections from river reduced in polarized imagery.
F8 + 9	Reduction of specular reflections from small stream in polarized imagery.
General	Elimination of specular reflections from roads in most of picture in polarized imagery, especially in center of town. See also Enlargement No. 4, Figure 16.
Leg 3-6 Exposures 84-98	
E + F4	Slight contrast increase in and around race track in polarized imagery.
Leg 3-7 Exposures 99-114	
General	No significant differences were noted.
Leg 3-8 Exposures 115-130	
B7	Reflections from the three roofs of buildings, slanted diagonally across the grid square, are reduced in the polarized imagery.

D7	The vegetation in the field is apparently polarizing the light reflected from it causing a difference between the polarized and the nonpolarized imagery.
H8 + 9 and D3 + 4	The light reflected from these roads is reduced by the polarizer and the road suffers a loss of contrast with respect to its background area.

Leg 3-9 Exposures 131-146

A1 + 2	Reduced reflections from street in polarized imagery.
F1 + 2	Road running into factory complex has increased contrast in the polarized imagery.
General	Roads in the center have generally increased in contrast in the polarized imagery, especially notable in intersections. An overall increase in contrast in the polarized imagery is also evident. See also Enlargement No. 5, Figure 17.

Leg 3-10 Exposures 147-162

General	No significant differences were noted.

Leg 3-11 Exposures 163-177

General	No significant differences were noted.

Leg 3-12 Exposures 178-192

General	No significant differences were noted.

Leg 3-13 Exposures 193-206

B9, C3, D1 + 2, F4, G3, and J4	Elimination of specular reflections from pond in polarized imagery.
I11	Elimination of reflection from water standing in field in polarized imagery.
General	Strong specular reflections from the roads, which obscure vision of detail in streets are eliminated in the polarized imagery, providing much more information in this area. See also Enlargement No. 6, Figure 18.

Leg 3-14 Exposures 207-224	
General	No significant differences were noted.
Leg 3-15 Exposures 225-246	
General	No significant differences were noted.
Leg 3-16 Exposures 247-267	
B8	Specular reflections from road in front of line of houses are reduced in the polarized imagery.
C8	Reflections from apparent vegetation in field behind single L-shaped house are reduced by polarizer.
D8	Reflections from the roofs of the three long buildings are reduced in the polarized imagery.
General	There is apparently a general increase in contrast in the upper third of the polarized imagery.

Flight 4

Leg 4-1 Exposures 1-12	
D4 right	Contrast increase in the parking lot in polarized imagery.
E4 left center	Contrast increase on and around steeple on building in polarized imagery.
I6 lower right	Windows on the side of the building with the long dark roof are more visible in the polarized imagery.
Leg 4-2 Exposures 13-24	
General	No significant differences were noted.
Leg 4-3 Exposures 25-35	
General	No significant differences were noted.
Leg 4-4 Exposures 36-50	
General	No significant differences were noted.
Leg 4-5 Exposures 51-63	
General	The polarized imagery has slightly greater density and contrast in the upper portion of the frame, although the overall exposure for the two frames is fairly well matched.

Leg 4-6 Exposures 64-75

General	Polarized imagery has higher density and contrast in upper third of frame.

Leg 4-7 Exposures 76-88

General	Polarized imagery has higher density and contrast in the upper third of the frame.

Leg 4-8 Exposures 89-101

E7 upper right	Roof of building appears in nonpolarized picture but not in the polarized imagery.
E7 lower left to E6 lower right	Street shows definite contrast difference between the polarized and nonpolarized imagery.
D9 upper right	Roof appears in nonpolarized picture but not in polarized imagery.
General	Several other objects which seem to appear only in the nonpolarized imagery due to specular reflections can be found. Higher density and contrast in the upper portion of the polarized imagery. See also Enlargement No. 7, Figure 19.

Leg 4-9 Exposures 102-113

General	The polarized imagery shows an overall slight contrast enhancement.

Leg 4-10 Exposures 114-127

General	No significant differences were noted.

Leg 4-11 Exposures 128-140

General	No significant differences were noted.

Leg 4-12 Exposures 141-153

General	No significant differences were noted.

Leg 4-13 Exposures 154-166

F7, E8 center	Roof of building appears in nonpolarized but not in polarized imagery.
F7	Streets appear lighter in the polarized imagery.
General	Overall increase in contrast in the upper portions

	of the polarized imagery. See Enlarement No. 8, Figure 20.
Leg 4-14 Exposures 167-181	
G4 upper	Large field appears lighter in polarized imagery.
General	Higher density and contrast in the upper portion of the polarized imagery.
Leg 4-15 Exposures 182-196	
General	Higher density and contrast in upper portion of the polarized imagery.
Leg 4-16 Exposures 197-213	
D4 center and upper right	Reflections from water-covered fields reduced in polarized imagery.
G6	Streets in town have reduced specular reflections in the polarized imagery.
General	Overall contrast higher in the polarized imagery.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

It was concluded early in the program that microdensitometer traces would not be useful within the level of effort of this program. It was hoped that the microdensitometer could be used to compare the contrast of photographs taken with and without a polarizer. However, there are several difficulties, both theoretical and experimental, with this type of analytical approach.

The theoretical difficulties arise from the fact that the contrast enhancement is a function of both the brightness and the polarization of reflections from the two ground surfaces being compared. Thus it is not possible to determine from two aerial photographs and such a small number of microdensitometer traces the inherent contrast enhancing power of the polarizer. Furthermore, by selection of the edges to be traced, one can prove nearly anything desired, using the edge traces as evidence.

The experimental difficulties arise from the high noise content of the traces from the shadow regions of the photograph. While this is the region where confusing specular reflections cannot occur and where the atmospheric penetration should be most important, the granular noise makes this measurement impossible without expensive raster scan and two-dimensional image analysis techniques. These techniques, while available, are well beyond the original intent and level of effort of this program.

Because of these two areas of difficulty, it was decided that the most valid presentation of results would be the original negatives. These negatives have been mounted in matched pairs (with polarizer and without polarizer) and are included as a supplement to this report. The photographic data needed to interpret each negative pair are supplied on the cardboard mount.

In addition to providing the original negatives, selected negatives have been enlarged for presentation in the report. These enlargements are provided to illustrate experimental verification of the three ways in which a polarizer can affect the contrast of an aerial photograph.

The prints are most helpful in illustrating the relevant phenomena. However, they must be interpreted carefully. Reference to the original imagery is recommended.

In general, the polarizer haze-penetrating potential has been observed to be significant when looking perpendicularly to the sun on a clear day. In other directions, the haze penetration is less effective, and in certain situations it is negligible. The haze penetration is also less effective against the aerosol haze encountered on a moderately hazy day. The polarization of specular reflections from both water and cultural targets was observed to affect the contrast of the photography obtained in this program.

The polarizer was observed to be most helpful when the camera was pointed below the sun and 90 degrees down from the sun. In this case, the polarizer helps to reduce both haze and heavy specular reflections from water and cultural objects.

It should be pointed out that there are some very important differences between the results which have been obtained with color. In the case of color, the reduction of specular reflections will, in almost every case, increase the color saturation (or color contrast) of the optical image. Also, the option of using a haze filter is not very attractive in color photography. The reason for this is that a haze filter simply reduces all the blue light, both image-forming and haze, proportionally. On the other hand, a polarizer reduces the ratio of haze to image-forming light, and thus improves the contrast of all three layers of the color film. Thus, use of a polarizer in color photography is very advantageous.

It is our opinion that future work in evaluating a polarizer for black-and-white film should be concentrated on long-range penetration of clear atmospheres. The evaluation should include the comparison of a polarizer and haze filter combination to a haze filter alone. While the combination represents a high price to pay in terms of filter factor, the improvement may also prove to be considerable.